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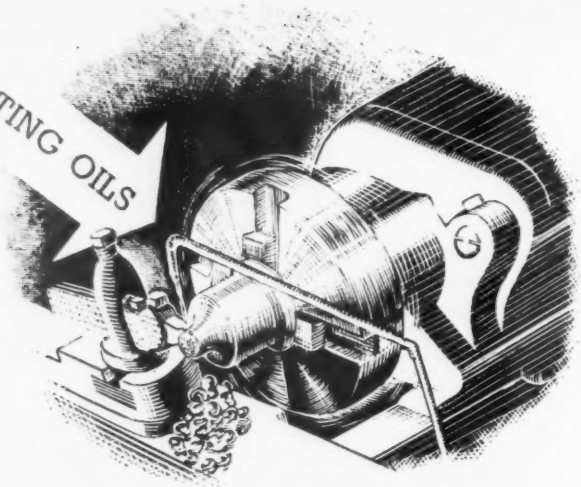

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OIL IS WHERE YOU FIND IT*

By WOODFIN L. BUTTE†

"OIL is where you find it." The expression is well known in the industry; it was used by old-time operators in derision of the newfangled methods which were being brought forward by scientists and professors for oil prospecting. These methods have long since proved their great worth, but the expression still persists with a slightly different meaning to indicate that, even when structures favourable to oil entrapment have been located, one is never sure oil is present until it is actually found with the drill.

I use the expression with a still different meaning: to emphasize that oil is where you find it—in other words, where nature put it, rather than where man wants it. In the unending search for oil, oil men have gone to the far corners of the earth; to the frozen wastes of the North, to the steaming jungles and to the arid deserts.

The bulk of the world's oil reserves are, by chance, located far from the heavily populated industrial areas of the earth, where the supplies mainly are consumed. From this one caprice of nature arises the vast and complicated economic, geographical and political implications of the oil industry to-day. You are aware, of course, of the tremendous amounts of oil that are beginning to move from the Middle East, but I must stress that it is not merely such recent developments to which I refer. In fact, the remoteness of oil sources from

* An address to the London Branch of the Institute of Petroleum on October 26, 1948.
† Chairman of the Middle East Committee, Standard Oil Company (New Jersey).

their point of consumption has been the characteristic of the industry since its inception, and has been a dominant factor in giving the industry the pattern it has to-day.

Truly, the world's oil resources and production are where you find them, and not where they are wanted. With the United States now a net importer of petroleum, there is not a single nation that produces sufficient to meet its own needs, with the exception of Mexico, and it accounts for but 1·5 per cent of the world's consumption. Leaving out of account the production from the United States and Russia, which is used largely within these two countries, about 70 per cent of the world's petroleum production is exported from the countries where it is produced.

In exempting the United States and Russia from these figures, and in admitting that the production of petroleum is used within the boundaries of the countries mentioned, I might seem to contradict my assertion as to the remoteness of oil sources from their point of use. This is not true, and with the petroleum production of the United States accounting for over 60 per cent of the world's total, an explanation of this seeming contradiction appears to be necessary. For the purpose of petroleum statistics, the United States is divided into five districts. Of the whole country's consumption 30 per cent is along the highly industrialized East Coast, to which supplies must come almost entirely from other districts. They come largely from Texas, travelling up to either 1200 miles over land by pipeline, or 2000 miles by tanker around Florida. I have suggested that the world's principal oil producing areas were remote and unbearable places. The natives of Texas will probably not admit this of their State; they must admit, however, that it is far from where their crude production is consumed. Less than a quarter of the Texas oil production is used in that State. Other areas of the country are similarly deficient of petroleum and are supplied from distant parts by pipeline. These, exclusive of oilfield gathering lines, now total 90,000 miles in length. I would point out that the remoteness of a large portion of the United States' supply of oil from the area of consumption was of serious consequence during the recent war. The sinking of many tankers bringing oil to the East coast forced the construction of two big-inch pipelines. These are each about 1200 miles long and together moved about 500,000 barrels of crude and petroleum products daily, about 50 per cent more than the present rate of consumption in the United Kingdom. Thus, I hope, it will be seen that my happily-endowed country is no exception to the rule; even there, oil is where you find it, rather than where you want it.

The great part of the world's production moves internationally, but little of it is used where it is found. The two great sources of international oil movements are located in the Caribbean and the Middle East areas. Except for the supplies for America and Russia, the world largely draws its oil from these two regions.

Broadly speaking, supplies from the Middle East take care of the Eastern Hemisphere, except for Eastern Australia and the western shores of the Pacific. Remaining supplies available from the Middle East move to Africa and Western Europe. The Western Hemisphere is generally self-sufficient and large supplies move to Western Europe to supplement those from the Middle East.

Refinery Location

Somewhere between the wells and the consumer there must be refineries, and I will say a word on these to complete the picture of the present international oil flow. The location of refineries, however, is not fixed, but is subject to the operation of economic and other forces. Not only is oil where you find it, but, at least from the practical point of view of

the oil man, centres of consumption are where he finds them.

If efficiency of operation and cost considerations were the only element in the picture, oil destined for international trade, or indeed for any movement by sea, would undoubtedly be refined at the point where the crude oil first reaches the coast. The advantages of such a refinery location are manifold. A refinery so placed can supply many markets; this permits it to be large. A refinery established at the point of consumption is more limited by the size of the single local market. Large-scale refineries, on the other hand, result in markedly decreased investments and operating labour —hence reduced refining cost per unit of throughput. Further, when a refinery supplies many markets, the relative proportions of different products, the quality of products and the seasonal variations in demand, each of which may be extreme for any single market, tend mutually to offset each other, resulting in less severe demands. Finally, about 10 per cent of crude oil is consumed in its refining, and refining at the source makes it unnecessary to transport these amounts used as refinery fuel or which are lost in the process of refining. The savings in transporting crude oil from an oilfield to the seaboard in a single large pipeline when compared with the movement of a variety of products in several smaller pipelines are, however, sufficiently great to offset this last factor, with the result that large refineries are usually built at the seaboard rather than at the oilfield.

When a local market (that is, one which a refinery supplies without reshipment of its products by deep-sea tanker) is large enough to support a refinery of substantial size, the choice, on a purely economic basis, between refining at the point where crude oil meets the sea and at the point of consumption, is very close. As a result, large refineries have also been built at ports adjacent to areas of great consumption.

Operating costs and efficiency are, however, not the only factors governing refinery location. Nationalistic policies, duty relief, and other laws may either compel an oil company to build small refineries in countries of relatively low consumption or make it economically attractive for them to do so, even though they would otherwise prefer to supply their markets in such countries from a large single refinery at the crude source.

World Oil Movements

This discussion of refineries, however, is a slight diversion from the primary consideration of the world's oil movements. To-day these movements are changing in a way, and with a rapidity, unparalleled in the history of oil.

The reasons for such changes are twofold. The first is the tremendous increase in the world's consumption of oil. In the last full year of pre-war operation, 1938, the world's crude production was about 5½ million barrels daily, and in 1952 we estimate that, to meet demands, it must be 11·2 million barrels daily. The increase that must take place between 1947 and 1952 is therefore 2·9 million barrels daily. This represents 54 per cent of the whole production of this giant industry of 1938. This new throughput must come from even more remote points. I must also stress that to-day the processes of refining are far more numerous and complex than those in use in 1938. Moreover, the costs of steel and labour are far above those that prevailed when the 1938 industry was being built. All of these factors will probably make the expenditures necessary to increase facilities to meet the 1952 demand equal to nearly the total cost of all the facilities in use at the beginning of the second world war.

Where is the new volume of oil required to come from? We would like it to come from sources as close as possible to the areas of increased consumption, but this is not the answer, for oil is only where you find it.

Although the Western Hemisphere is producing the bulk of the world's oil that is no indication of its potentiality, compared with that of other areas, for the future. Its reserve supplies relative to the current production rate are far less than in any other important producing region. For example, the United States, while producing 62 per cent of the world's oil, has only 32 per cent of the world's proved resources. Although new reserves will be discovered in the Western Hemisphere, there is reason to believe that proved reserves will not increase greatly. Some competent authorities feel that United States' production will never exceed its present level by more than 5 or 10 per cent. Regardless of the precise figure, it seems evident that never can the Western Hemisphere have the reserves with relation to production that the Near East is known to have.

It is sometimes stated, but erroneously, that the oil supplies of the United States will be exhausted in eleven years. This is very misleading. New reserves are being discovered to-day, even in the United States, at about the rate at which oil is being withdrawn. Even with no new discoveries, the present resources could not be exhausted in twelve years. Without new reserves, production would taper off over a much greater number of years.

Venezuela, Russia, and some miscellaneous producing areas are in a better position to increase production relatively than the United States, and the Middle East is in a far better position. The proved reserves there represent 104 years' supply at present production rates, but Middle East supplies are capable of being vastly increased.

By far the greatest production in the Middle East comes from Iran, in which country production has been of important magnitude for the longest time, having reached 100,000 barrels daily twenty years ago. This oil largely moves to the head of the Persian Gulf and is refined at Abadan; some part, however, is shipped from this point as crude oil.

The next oldest operation is that in Iraq, where production at almost the present level was reached in 1935. This oil comes to the ports of Tripoli and Haifa on the eastern Mediterranean.

Saudi Arabian production did not reach 100,000 barrels daily until two years ago. From this source about 100,000 barrels daily are refined on the Persian Gulf at Ras Tanura, the rest being shipped as crude oil. The rapid rise of production there, as compared with that in Iraq, is attributable, among other things, to the fact that the fields are near the seaboard, whereas expansion of the Iraq supply requires the construction of pipelines over 500 miles long.

Development in Kuwait was delayed by the war, but is now very active. 45,000 barrels daily came from this area last year, but it is expected to have averaged three times this amount during the course of 1948. As in Saudi Arabia, the producing fields are close to the coast.

As a rough guess it has been estimated that production from these areas may well reach 1,838,000 barrels daily by 1952. Even this high production rate corresponds to a depletion time for the total reserves of 32,000,000,000 barrels of forty-seven years.

Mention was made that nearness to the seaboard has allowed Kuwait and Saudi Arabian production to increase, whereas development of the Iraq fields deep inland has been retarded by the difficulties of installing pipeline facilities. Two 16-inch Iraq lines, which together will allow Iraq production to increase to 275,000 barrels a day, are under construction, and a 30-inch line to double this latter figure is also to be built by the Iraq Petroleum Company. But even though the Persian Gulf fields have outlets to the sea, much of their output is destined to come through the Suez Canal,

and the long haul of 3200 miles around the Arabian peninsula is both very expensive and requires a large investment in tankers. Whereas a T.2 tanker will move 4400 barrels daily from Haifa to the United Kingdom, this is reduced to 2100 barrels a day if the oil must be moved from the Persian Gulf. Movement by pipeline across the top of the Arabian peninsula saves about 2000 miles of tanker run, and also saves steel and manpower. Therefore, the relative merits of movement by such pipelines, or by very large tankers, are being considered by all of the major interests operating in the Persian Gulf.

The Trans-Arabian Pipeline Company, a subsidiary of the Arabian-American Oil Company, is constructing a 30-inch line which will move Saudi Arabian crude 1075 miles to Sidon in the Lebanon, and will have a capacity of 500,000 barrels daily.

The Middle East Pipeline Company, owned by Anglo-Iranian, Jersey Standard and Socony, is planning a 34-inch and 36-inch line to move both Iranian and Kuwait crude to a point in Latakia on the Mediterranean. Gulf, who have a 50 per cent interest in the Kuwait concession, and Shell, who are purchasing a portion of the Kuwait crude, are considering another 34-inch and 36-inch line from Kuwait to the Mediterranean.

Together the new lines which I have mentioned as proposed, or actually under construction, will have a capacity of just over 2,000,000 barrels daily, and will cost over £250,000,000. Construction of all these lines is being retarded by prevailing unrest in the area and by the world-wide shortage of steel. It is doubtful whether the whole programme indicated can be completed before about 1956. Further, it seems evident that sufficient of it cannot be completed to allow the 1,800,000 barrels daily of Middle East crude, indicated as necessary to meet world needs in 1952, to reach markets without a continuance of heavy tanker movements around the Arabian peninsula.

Eventually, with demand increasing in the Western Hemisphere and with a limitation on the increase in production which is possible there, and with the plentiful supplies from the Middle East when the pipelines are completed, we anticipate that the Eastern and Western Hemispheres will become almost independent of each other for petroleum supplies.

I have, in this talk, emphasized the physical factors which appear to be controlling the development of the world's oil picture, and to base such observations and predictions as I have made on these. But I do believe these physical factors cast their own shadow forward. The task ahead for the oil industry is stupendous. If I were to single out the thing foreshadowed which impresses me most, it is that the oil required to meet the greatly increased demands foreseen, and particularly that required to power and fuel the reconstruction of Europe, must come through the pipelines which are as yet but dotted lines on blue prints, and from wells which are as yet undrilled in the remote fields of the Middle East. This needed oil must come from there, because that is where you find it.

"MODERN AMERICAN POWER STATION PRACTICE"

In 1944 G. D. Elliott, a director of John Thompson Water Tube Boilers Ltd., visited the United States, and in this book of 57 pages he describes some of the highlights of American power-station practice. The book includes information on boiler design, construction and operation, on stokers, pulverizers and burners, on turbo generators, and a description of the hydrogen-cooled generator. Copies are available from the company at Ettingshall, Wolverhampton.

TECHNICAL DATA AND ITS PRESENTATION

Two publications of considerable value and importance to the compiler of technical reports and the writer of technical books have recently made their appearance. The first of these, *The Presentation of Technical Information** by Reginald O. Kapp, is based on four public lectures given at University College, London, in 1947. So great was the response that they were repeated in the lecture theatre of the Institution of Electrical Engineers.

Professor Kapp has done a valuable service to the world of science in making his lectures available to a far larger audience than could ever be gathered together in any lecture hall, or even in a series of lecture halls. For, as he rightly says in his preface, there is "a serious under-estimation of the magnitude o the problem that the executive engineer or scientist has to solve in the course of his professional work when he is presenting technical information or reasoned argument. . . . Teach a man to think clearly, and he is likely to express himself clearly; teach him to think about the person addressed, and he will have learned the first lesson in the art of conveying information effectively from mind to mind. But teach him only how to turn out well-constructed sentences and he will fail badly in the art of exposition."

This volume is one which can be read and re-read with advantage by all writers of technical literature.

The second book is *Technical Literature*† by G. E. Williams, who is head of the editorial department of the Institution of Electrical Engineers. The subtitle of this book is "Its preparation and presentation", and the subject-matter is divided approximately equally into consideration of these two matters in their logical sequence. Thus, the first half discusses the method of presenting technical material from the preparation of the outline of the contents to the passing of the final draft.

In dealing with the preparation of manuscripts stress is laid on the desirability of setting these out in the form required by the particular learned society to which the paper is to be submitted. If authors of papers could be induced to do this Mr Williams will have earned the gratitude of many editors of technical publications. In fact, many would echo the words of the editor of *The Railway Observer* who, in his October 1948 issue, wrote: "The more time we can spend editing and the less rewriting, the better *The Railway Observer* will be".

Much useful information is given in the book for the benefit of editors and sub-editors. The method of estimating from a manuscript the length of the printed article seems to be unnecessarily complicated, bearing in mind that it produces only an estimate—an approximate word-count is usually sufficient for such estimates.

This again is a book which should be part of the equipment of a writer of technical literature and also of the editor of technical journals.

Both these volumes have a chapter on the choice of words, and this opportunity is taken of bringing to the notice of our readers that excellent volume *Plain Words. A Guide to the Use of English* by Sir Ernest Gowers. Published by H.M. Stationery Office (price 2*s.* net) in April 1948, it was reprinted in the same month and again in June. Its 94 pages of text matter, although primarily written to "help officials in their use of written English", should be of considerable use to all writers. G. S.

* Constable & Co. Ltd., London, 1948, pp. 147 + xi; 6*s.* net.
† George Allen & Unwin Ltd., London, 1948, pp. 117; 7*s.* 6*d.* net.

A VISIT TO A TRINIDAD "WILDCAT"

ON September 11, 1948, with the kind permission and co-operation of the United British Oilfields of Trinidad Ltd., members of the Trinidad Branch of the Institute of Petroleum had the opportunity of seeing the layout and operation of a modern deep-well drilling rig. This was at U.B.O.T.'s wildcat at Tablelands, in the south-easterly part of the island.

This well is being drilled as a deep Oligocene test to about 10,000 ft. It is of interest to note that this is the first deep wildcat in the island on which diesels have displaced steam engines as prime movers. The present outfit in use here is the Oil Well Supply Company's No. "96" Rig.

The "96" hoist is capable of drilling to 12,500 ft with 4½-inch drillpipe and to 16,000 ft with 3½-inch drillpipe. It is equipped with six hoisting speeds, three rotary speeds, and a reverse. As practically all the equipment such as clutches, brakes, and throttles are air operated, the driller can perform most operations from the centralized control panel, as seen in Fig. 1.

The motive power for the hoist and main slush pumps is supplied by a group of three Davey-Paxman 12-RPH diesels. At 1100 r.p.m. each engine develops 360 h.p., giving a total for the rig of 1080 h.p. It was necessary to send the engines, which were made in U.K., to the United States so that they could be assembled with the draw-works and compound drive on the special substructure supplied for the "96" rig. These engines are similar to those which were widely used for marine work during the war. Scoop-controlled Vulcan-Sinclair fluid-drive couplings are fitted on the output ends of each engine shaft to cushion the drive to the main transmission and smooth out the load shocks and fluctuations which might otherwise be imparted to the engine crankshaft.

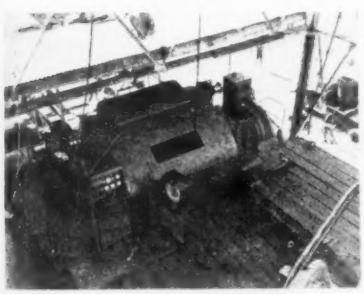


Fig. 1. The centralized control panel.

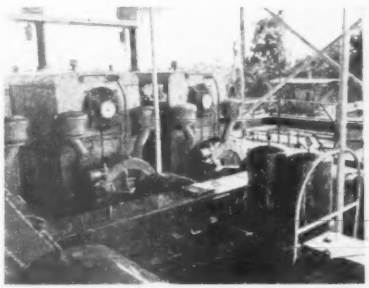


Fig. 2. The compound drive.

Fluid couplings give a wide range of speed control and permit full pressure of the slush pumps at zero speed, thus giving the diesel engine the equivalent characteristics of a steam engine. By means of the "Oilwell" 1000 Compound Drive, seen in Fig. 2 together with the engines, it is possible to select and compound any of the three engines to suit immediate power requirements. Most of the power used in drilling is consumed by the slush pumps in keeping the mud flush circulating in the hole.

At the time of the visit the rotary table, an Emsco JCS-20½-inch made in the U.K., was driven by a totally-enclosed chain drive from the draw-works. It will later be unitized with a Paxman diesel, complete with scoop-

controlled fluid coupling and gearbox, to form a completely independent rotary machine.

The mud plant at the well site is self-contained; the general layout is shown in Fig. 3. The four pits in the background have a total capacity of about 3000 barrels; here mud is stored and its weight built up as required. In view of the high pressures normally encountered in the Oligocene formations in Trinidad, it will be necessary to carry weighted muds of around 115 to 125 lb per cubic foot. The weight of the shale mud, which normally is about 85 to 90 lb per cubic foot, will be increased by the addition of barytes.

The pumps used in the plant may be

Fig. 3. Mud plant is self-contained.

seen in the foreground of Fig. 3. These are Emsco D-12, $6\frac{3}{4} \times 12$ inch, driven by Buda-Lanova diesels and are chiefly used for jet-mixing work, building up the weight, and pumping fresh mud to the mud tanks. One of the three pumps, that on the extreme left, is used to circulate the mud through the mud cooler seen in Fig. 4. Formation temperatures of around 150° and 190° F can be expected at depths of 5000 ft and 8000 ft respectively, so that it is essential to cool the mud in order to maintain the efficacy of the chemicals added to the mud to reduce its viscosity.

Two "Oilwell" Wilson-Snyder 220-P

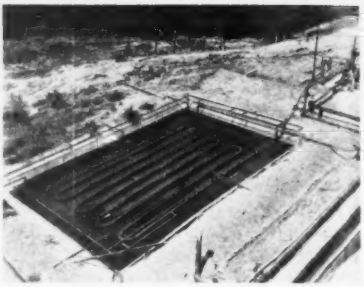


Fig. 4. Here the mud is cooled.

power pumps keep the mud circulating from the mud suction tanks, down the hole, and back along the elevated mud ditch into the mud suction tanks again. Each of these pumps is capable of delivering 355 U.S. gallons per minute at a working pressure of 2450 p.s.i. with 5-inch liners, for an input h.p. of 600. (See Fig. 5.)

Two Link-belt NRM-124 unitized vibrating screens separate the formation cuttings from the circulating mud in which they were brought in suspension from the bottom of the hole.

Although most of the equipment on the rig is of American origin, there are certain items of British manufacture. These include the derrick, travelling block, blockline, and, as mentioned before, the engines and the rotary table. Like the rotary table, the travelling block is of Emsco manufacture (made

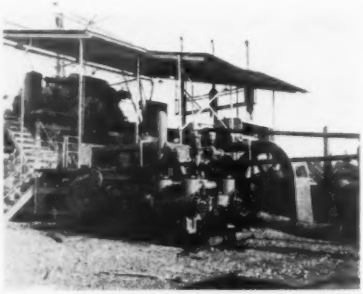


Fig. 5. Mud pumps.

under American licence in U.K.). The 1¼-inch right-hand ordinary lay "Seale" type hemp cored blockline is made by British Ropes Ltd. and has an ultimate breaking strength of approximately 50 tons.

The fully galvanized derrick (Fig. 6) is a Mitchell Engineering Group product built to API specifications with a load-carrying capacity of 952,000 lb and stands

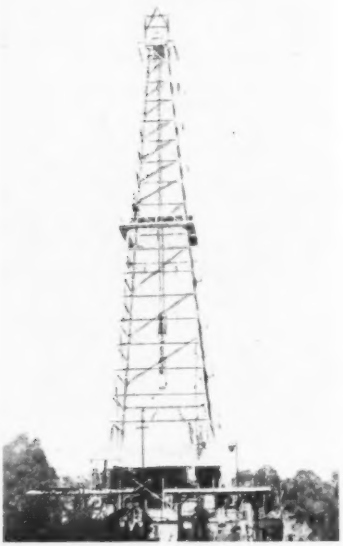


Fig. 6. The 136-ft. derrick.

136 ft high on a 30-ft square base. It is erected on a standard API Type "B" substructure, 12 feet 6 inches high to suit the engine and compound drive substructure and the plug substructure of the draw-works.

The fuel for the engines is kept in two 250-barrel tanks, and brought to the well site by tank truck from Princes Town station, to where it is delivered by rail tank wagons from Pointe-a-Pierre.

Water is supplied by I.C. engine-driven pumps directly to the rig from a reservoir built about two miles away from the location, and a reserve storage of approximately 700 barrels is maintained in steel tanks at the location for emergency.

The visit was enjoyed by member and visitor alike, and was of particular interest in view of the fact that the rig is, at present, the first of its kind in Trinidad.

SCOTTISH BRANCH

A meeting of the Scottish Branch of the Institute was held at the Heriot-Watt College, Edinburgh, on November 26, 1948, when the chair was taken by Robert Crichton, chairman of the branch.

The lecturer was R. Stansfield, and his subject "Engine Tests of Lubricating Oils". Mr Crichton, introducing Mr Stansfield, said that he was well qualified to speak on this subject, having been in charge of the engine research department of the Anglo-Iranian Oil Co.'s research station at Sunbury-on-Thames since its inception over twenty years ago.

About fifty members and visitors were present, and at the end of the address a number of questions were answered by the lecturer.

In his lecture Mr Stansfield pointed out that engine tests of lubricating oils must correlate with service behaviour if they are to be useful, but the service behaviour of a given lubricating oil can be either satisfactory or unsatisfactory depending on the particular engine in which it is used and on the conditions of duty. No single laboratory test is sufficient to forecast service results and only tests made in engines are of much value.

It had been found that the type of fuel used had a significant effect on the behaviour of the lubricating oil and on engine deposits, both in diesel and petrol

(Continued on page 27.

THE AIRBORNE MAGNETOMETER FOR MINERAL EXPLORATION*

By Wing-Comdr. D. N. KENDALL, O.B.E.†

In elementary physics one is taught that the earth is a giant magnet with its poles at the north and south. A magnetic field exists around the magnet with lines of force that proceed vertically from the South Pole, gradually turning until they enter the North Pole. It follows therefore that the lines of force are horizontal at the equator and nearly vertical at the poles. The unit of measurement of the magnetic force is a gamma, and the earth's field varies from about 25,000 gamma at the equator to about 60,000 gamma near the poles.

Certain materials, which are abundant in the earth, are known as ferro-magnetic and when placed in a magnetic field absorb part of that field, become magnetized, and give off their field. Many other materials are para-magnetic and cause small local changes in the earth's magnetic field.

The magnetic field at any point is a function of the size and length of the magnetic body and the distance from it. It follows, therefore, that if one could measure the field at a given point and if one knew the length of the body, its depth could be computed. This is an important fact in geophysical interpretation.

In very general terms, then, it follows that physical information of great value to a geologist could be provided if, in any locality, the earth's magnetic field was taken as a datum and the plus or minus for this was recorded on a map for a large number of points in the area. It would be possible to outline the location below the ground of magnetic highs and lows.

There is nothing very new about this, and it has been done on the ground with an instrument called a magnetometer for a great many years. It has been used widely in exploration, but is fairly slow and expensive. Roughly speaking, the ground instrument consists of a short length of metal, mu-metal, which is capable of absorbing and shedding a magnetic field very rapidly. It is surrounded by a coil which amplifies the record. The coil is levelled in the vertical position by means of a bubble so that the vertical component is recorded, i.e., only part of the earth's magnetic field given by the formula "vertical component equals total force cos the angle between them".

The idea of putting a magnetometer in an aircraft was first tried in Russia in 1915. There was also some development for naval purposes in England about the same time. However, development was largely dropped between the wars. In 1943, however, the German U-boats, which up till then could be located by radar when they surfaced, became equipped with a device for air intake which enabled them to remain permanently submerged at sea. An alternative method for locating them had to be developed, and the Magnetic Air Detector (M.A.D.) was brought into use by the U.S. Naval Ordnance Laboratory. This was, in effect, an airborne magnetometer.

The air problem was, however, a much more difficult one than the ground, since clearly the aircraft itself gave off a large and varying magnetic field of its own, and it is extremely difficult to maintain in an aircraft any instrument in a truly vertical position. Gyros have not the necessary precision on the whole. Besides, near the equator the earth's

* Precis of a lecture delivered to the Royal Geographical Society.
† Managing Director, Photographic Survey Co. Ltd., Canada.

field is more or less horizontal, and in consequence the vertical component hardly exists.

The U.S. Navy solved the problem by constructing an instrument to record the total field, and by placing it in a towed container (the "bird") well behind the aircraft, where it would not be affected by the aircraft's magnetic field. The instrument consists basically of three coils (x, y, and z) at right angles to each other. It follows that if coil x, the recording coil, is aligned exactly into the total field, coils y and z, being at right angles to it, will record zero. As soon as coil x wanders slightly, coils y and/or z take up small components. The instrument is so constructed that the impulses in coils y and z activate servo motors which immediately bring coil x back into the total field.

For certain types of work, particularly oil exploration where small variations in the basement rock are being looked for, it is necessary for the magnetometer recordings to show differences as small as two gamma. Unfortunately the servo motors cannot reorientate the x coil fast enough for this accuracy and sudden tilts would give unknown errors of relatively high dimensions. It so happens, however, that for small angles the sum of the squares of the magnetic components in the y and z coils equals the loss in the x coil. These are, therefore, added automatically to the record and no significant error appears so long as the x coil is kept within five degrees of the total field, an easy specification.

The final airborne magnetometer is thus an instrument which records in the form of a continuous profile the small local variations in the total field and which is fully compensated for errors which arise when the recording coil wanders temporarily from the total field.

The earth's field is not constant and varies slightly throughout the day. This is known as drift and has to be eliminated in the piloting. Instrument drift also exists, particularly if it is not temperature compensated. A constant electrical flow from the batteries to the instrument is also an absolute requirement.

To appreciate the plotting method, brief reference must be made to the ancillary instruments in the aircraft. These consist of the following:

(*a*) *Easterline-Angus Recorder*, which records the continuous magnetic profile;

(*b*) *Radio Altimeter*, to give the exact height of the aircraft above the ground;

(*c*) *Data recording camera*, to record ranges from radar beacons (when employed), aircraft altitude, barometric height, temperature, magnetic datum, etc.;

(*d*) *Location camera*, a 35-mm. camera which records continuously the area immediately below the aircraft so that the magnetic profile can later be plotted with the aid of the photographs on to a base map.

It should be mentioned that over water the location camera is, of course, useless and has to be replaced by a radar system giving the ranges from beacons at known points.

A normal airborne magnetometer survey goes through four main stages, i.e., planning, flying, reduction of data, and interpretation. The planning stage involves a study of existing geological information to determine the direction of flights and the spacing of flight lines. It also involves securing high altitude vertical air photographs for use later in flying and the plotting of the data.

The flying stage consists first of the establishment of base lines and then of the stripping.

The reduction of data is discussed more fully below, but it must be emphasized at once that it is laborious and occupies perhaps ten men in the office for every one flying.

The geophysical interpretation is a highly specialized job calling for much practical experience which only time can

provide. To produce a map with the magnetic data marked thereon is a fairly complex survey problem which requires organizing. The map is factual; to assign a meaning to the magnetic data calls for an expression of opinion, whose reliability is to a large extent a factor of the experience of the geophysicist concerned.

Returning to the problem of reduction of data, the profile as obtained from the aircraft varies in the following way:

(*a*) in horizontal scale due to changes in the ground speed of the aircraft;

(*b*) in vertical scale due to the necessity for the operator to change his vertical scale (or intensity) in order to keep the ink profile on the recording paper;

(*c*) in datum, again to keep the record on the paper;

(*d*) in axes due to drift.

In addition the profile is recorded in curve linear co-ordinates which have to be rectified to rectilinear.

An instrument can be built of a complex pantograph type which will correct for all factors except drift in one step. Briefly the system is to plot at intervals, say every five miles, points on the profile record which coincide with the ground, by means of the 35 mm vertical record. The aircraft speed can then be accurately calculated to give horizontal scale. Vertical scale is given by recorded data. Thus a profile can be drawn out to a common scale.

To eliminate drift it is necessary to return to the base line referred to earlier. Base lines to be established will vary according to the area, but for small areas will consist of one across the centre of the line of flights. The base line is flown in each direction giving two similar profiles. However, during the time of flight, drift will have caused a few gamma difference in the total field at the starting point. It is now assumed that this variation was linear and the correction is applied to the whole profile. A common datum now exists for the area to be surveyed and each profile of the flight is corrected to this by identifying the point at which it crosses the base line and adjusting the profile to it.

It is now a comparatively simple matter to plot up the profile onto a good base map, and with this done the geophysicist takes over. The drawing in of the contours, joining points of equal magnetic intensity, requires geophysical and geological knowledge since often various alternative ways of effecting the link-up exist. As already explained, the subsequent interpretation of the results requires further specialized knowledge.

Turning now to the question of instrument availability, in the U.S.A. at least five instruments are on the market, three types being in actual operational use, i.e., the M.A.D. (designed by the U.S. Naval Ordnance Laboratory and now built by the Gurley Company, Troy, New York), the Gulf Oil instrument, and the Heiland instrument. All three record the total field. In Canada Hans Lundberg has developed an instrument to record the vertical component and to be carried in an aircraft.

As regards work being carried out, the following is impressive and represents only a part of surveys completed:

(*a*) *The U.S. Geological Survey* have several M.A.D. instruments and have surveyed 180,000 square miles in the U.S.A. and Alaska.

(*b*) *The Geological Survey of Canada* have three M.A.D. instruments and propose to survey in time the whole Dominion, issuing the data with their geological sheets.

(*c*) *Gulf Research and Development Company* have surveyed large areas in Canada with their own instrument on their own behalf, mainly for oil.

(*d*) *Gulf Research Licencees.* The two U.S. licencees have in eighteen months completed about £1,000,000 in surveys, mainly for oil

companies. This represents at least 250,000 square miles. The largest contract was in the Bahamas, but other large jobs have been in Venezuela, Colombia, Cuba, the U.S.A., and Canada. A great deal of further work is contemplated.

The main reasons for the importance of the airborne magnetometer may be summarized as follows:

(*a*) *Elimination of ground interference*. On the ground the record is confused by numerous small anomalies from small and insignificant bodies at or near the surface. These are eliminated with the airborne instrument.

(*b*) *Depth determination*. With the air instrument the same body can be flown over at two different heights thus enabling the size and depth of the body to be calculated with reasonable certainty.

(*c*) *High accuracy*. The airborne instrument is extremely sensitive and with automatic orientation and vector squaring can provide profiles which can be read to one gamma. The continuous profile is a great advantage over the spot recordings made on the ground.

(*d*) *Speed*. The normal output per instrument should be 7000 line miles per month, or 100 times ground speed.

(*e*) *Low cost*. Given reasonable areas the cost should be one-tenth of ground costs.

(*f*) *Accessibility*. With methods developed no area is inaccessible whether over trees, swamp, desert or water.

It is believed that this instrument is only the forerunner of other airborne geophysical instruments and it will suffice to say that promising development is in hand in the U.S.A. and Canada in connexion with radio acitvity (geiger counters), electro-magnetic surveys, gravity meters, and the installation of instruments in helicopters.

SAFETY IN CHEMICAL WORKS

UPWARDS of two hundred delegates attended a conference on accident prevention in chemical works, held at Harrogate from October 29 to 31. The conference was sponsored by the Association of British Chemical Manufacturers and was organized on their behalf by the Royal Society for the Prevention of Accidents.

The opening address was given by Sir Ewart Smith, Technical Director of Imperial Chemical Industries Ltd. With him on the platform were Sir Harold West of Messrs Newton Chambers and Co. Ltd. (who took the chair) and Sir Harry Jephcott, Chairman of the Council of the A.B.C.M.

J. Davidson Pratt, Director and Secretary of the A.B.C.M., was chairman for the working sessions of the conference, when the following papers were given:

"Health Hazard—Present and Future" by J. Gwynne Morgan, C.B.E., T.D. (Mond Nickel Co. Ltd.).

"Safety in Chemical Plant Design" by J. E. Braham (Imperial Chemical Industries Ltd.).

"Safety Organization" by H. R. Payne (Chairman of the Works Safety Committee of the Association of British Chemical Manufacturers).

"Safety Records" by H. G. Winbolt (Director of the Industrial Safety Division of the Royal Society for the Prevention of Accidents).

"Clearance Certificates" by A. G. Palmer (Gas Light and Coke Company).

The final session consisted of a two-way brains trust in which questions were answered both by a panel of experts and by those in the body of the hall.

A few copies of the papers are available and will be supplied on request by the Association of British Chemical Manufacturers, 166 Piccadilly, London, W.1.

RANDOM RECOLLECTIONS

By JAS. S. PARKER (Fellow).

THREE islands in the Caribbean are interested in the oil business. Trinidad is a producer and refiner. Curacao and Aruba house refineries in the world's largest bracket. All these refineries operate along similar lines for motor and aviation gasoline, utilizing mainly the cracking process. There is another similarity. They all smell the same. Aruba only have arranged it so that the constant trade wind blows across the refinery out to sea.

Three islands in the Caribbean are interested in the tourist trade. Trinidad has ideas about building a whacking big hotel at Maracas Bay on the north coast. Curacao is a free port and the proposal is to add a Casino to that advantageous feature. Aruba also has a Casino under consideration. Its ace feature, however, is that it is easier to secure a divorce in Aruba than in Reno.

A modern innovation which is operated by all Caribbean oil companies is the Personnel Department. This was aptly described as the oil companys' Cook's agency. In the old days, after struggling through Customs and all other red tape departments, one generally made one's way to the field under one's own power. Nowadays "Personnel" take over control almost before the anchor is dropped and make all required arrangements until the anchor is pulled up again.

Pan American and K.L.M. are competing for all the Caribbean air business. Both are on a par for flying skill and both fly American planes. No British commercial plane or British-flown commercial plane was sighted at any air-port.

During the war a duplicate cracking unit to that erected at Heysham was under construction at Thornton, near Ellesmere Port. Erection never advanced beyond the foundation stage, at which point the complete unit was shipped to Curacao. This unit is in full operation at the C.P.I.M. refinery where it is known to all personnel as the Thornton Unit.

Aruba refinery of Lago Oil & Transport.

(Above)
Horton spheroids.

(Left)
The tank farm.

It was the dry season in Curacao so it rained. It was the wet season down the west coast of South America but rain was long overdue. Meteorology is not an exact science.

The C.P.I.M. had an original idea. There was surplus tank storage and a shortage of shed storage. A bottom plate was taken off a storage tank of about 80,000 brl capacity and the tank used for storing sacks of cement. With a reversal of the storage positions the plate could be welded back on to the tank.

Time marches on! There were look-boxes of the type associated with the continuous distillation bench still in full operation on one unit in the C.P.I.M. refinery. Almost cheek by jowl with the latest in precision fractionation.

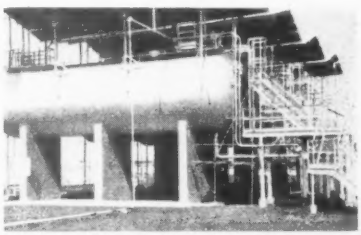
Piscadera Bay Hotel overlooking a coral-bottomed bathing pool had acquired the South American habit of music on all occasions by radio loud-speaker. The outside bedrooms in the pre-war wooden style general in the Caribbean were scheduled for modernization.

The pontoon bridge between Punda and Otrabunda in Willemstadt still opens to allow tanker passage to the refinery.

The toll only has been modernized. Formerly it was so much for boots, about half for alpargatas and free for bare feet. Nowadays a standard rate is in operation.

The shops in Willemstadt are fully stocked. In comes a tourist ship, decants seven or eight hundred passengers and the shops in Willemstadt are under-stocked. And if in the process the plain figures on all items are translated as dollars instead of guilders, who worries. Not the shopkeeper at any rate.

The Hotel Americano in Willemstadt still flourishes. My stay was too short to investigate the present position of the Globe. You don't know the Globe? It was a pub with a light outside the door in a large glass ball. A map of the world sprawled over the ball and on it, greatly exaggerated, Curacao was marked. At the termination of an evening's entertainment in the Globe the drill for the crews of the lagoon ships, when lagoon ships were lagoon ships, was to wipe Curacao off the



Aruba refinery of Lago Oil & Transport.

(Above) *Propane storage tanks at the jetty.*

(Right) *A general view of the refinery.*

map. The pub owner kept a stock. It paid.

Gold is present in Aruba but was never an economic success. Phosphate is mined and 78 per cent of the total world's supply of aloes is produced on the island. So says the local guide book. As a side line there are two oil refineries, the Eagle Oil near Orangestad, which is comparatively small scale, and the Lago Oil and Transport near San Nicholas, which is one of the world's largest.

Lago is the only refinery in the Caribbean with a cat-cracker. This was built early in the war and is of fluid catalyst type with reactor perched high over the regenerator, giving a 230-feet height which dominates the flat landscape. Its last operating schedule was for 15 months duration, which would indicate that the bugs have been ironed out of this type of operation.

One interesting point not generally known is that during the war a U.S. destroyer suffered an explosion in its fuel oil bunkers which was diagnosed as having been due to gas evolution from the fuel oil. The refineries trended to look down their nose at this but investigation by them proved it to be correct. There was a certain amount of gas entrainment in fuel from cracking operations. This has necessitated, for U.S. Navy purposes, further treatment of cracked fuel to remove the entrained gas.

Lago is, as far as is known, the only refinery shipping propane in bulk. The propane is stored in four 37,000-U.S. gal pressure tanks alongside the jetty and is pumped thence to the tanker through a 4-inch line with a 2-inch return vapour line to the loading tank. The special tanker has four pressure tanks each of 25,000-U.S. gal capacity. Cobalt nitrate indicators in $\frac{1}{4}$-inch spiral tubes are attached to the pipelines to ensure that the propane is loaded dry.

All fresh water is either brought in by tanker or made from sea water by evaporation and condensation. Lago do their tar cooling with salt water on the evaporation circuit, regulating temperatures so that the salt water run off from the tar coolers to the salt-water evaporators is maintained at about 165° F. Both the C.P.I.M. and Lago gunite the plates of their salt-water coolers, and this practice has given markedly successful anti-corrosion results.

The C.P.I.M. and Lago have an excellent arrangement by which there is an interchange of ideas on corrosion and similar problems at six-monthly intervals, alternating between the refineries. This has the added advantage of giving the technical groups concerned a break. Both refineries thus trend to operate in step on such problems.

For firing purposes both refineries make extensive use of pitch, mainly from cracked residue, on the closed circuit principle bleeding off a percentage to the burners. The C.P.I.M. use pressure-fed Peabody burners at an oil temperature of about 210° F operating for a somewhat smoky flame which is optimum for ash forming conditions. The ash is collected for vanadium recovery, the content being around 20 per cent calculated as V_2O_5. Lago practice for pitch burning is normal but for fuel oil burning they trend to the use of the individual motor-driven cone type of burner with air pressure on the outside to project forward the oil spread. This gives a

Tankers at the Aruba jetties of Lago Oil and Transport.

satisfactory short flameburst with excellent atomization.

The C.P.I.M. trend toward the Pacific type of hot oil pumps—centrifugal, steam, turbine-driven. Lago use motor-driven Byron-Jacksons, the electric motors totally enclosed and water-cooled.

The first lagoon ships were converted monitors of 400-ton crude carrying capacity. From these the 2000-ton shallow draft lagoon tankers were evolved. The next step was to 4000-tons. Now the G type is coming into service with 6000-ton carrying capacity. The C.P.I.M. and Lago operate between 40 and 50 lagoon tankers each on the milk run to Lake Maracaibo.

Lago are fortunate in having a coral reef off shore enclosing a large expanse of safe water. The youngsters, as usual, are expert swimmers and make extensive use of frogmen's flippers.

For those interested in the question of largest refineries the C.P.I.M. crude oil intake was of the order of 350,000 brl/day and that of Lago 410,000 brl/day.

Having off-loaded at Carribean oil centres the majority of the I.P. *Brochures* carried, the remainder were thrown in loosely on top of the suitcase. Coming into Balboa the pilot lost height fast, the only occasion on the trip, with the result that semi-deaf passengers were ushered through the U.S. formalities. A woman Custom's Officer, with completely expressionless face, picked up a *Brochure*. What is this? In English. The publication of a British scientific society. The boss is called in. Joint consultation. The outcome from the boss. Have you any samples? One could probably think up a number of replies to that but the safest one was given. No. South America is scared of Communists.

(*To be continued.*)

Cechi-lined main road in Curacao.

ROYAL DUTCH/SHELL RESEARCH

THE Royal Dutch/Shell Group has formulated a research programme for 1949 with an estimated expenditure of £6 million. The programme covers every aspect of the oil industry from prospecting for crude oil to the final utilization of the products.

About 4000 persons are employed on research activities for the Group in its research laboratories in the U.K. (Thornton), the Netherlands (Amsterdam and Delft), and the U.S.A. (Emeryville, Wood River, Houston, Wilmington, and Martinez). In addition experimental farms have been established at Woodstock, Kent, and Modesto, California, for the investigation of insecticides, fungicides, and other agricultural problems.

For 1948 the Shell Development Co. at Emeryville gained the "Award for Chemical Engineering Achievement" of the American Institute of Chemical Engineers. This was given for the company's work on the manufacture of synthetic glycerine from petroleum. In this connexion it is recorded that the Shell Company has completed the world's first full-scale plant for this process at Houston, Texas. Costing over $9 million the plant will produce 35,000,000 lb of synthetic glycerine annually.

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PULVERIZED FUEL

By ARNOLD FITTON*

IN June 1947 a well-attended Conference on Pulverized Fuel was held at Harrogate under the auspices of the Institute of Fuel. Over 50 papers were discussed covering every aspect of the preparation and utilization of pulverized fuel and the subject was obviously of wide interest. An endeavour has therefore been made in this paper to make a general review of the present position.

The progress which has been made in pulverized fuel during the last 20 years is indicated in Fig. 1 which shows the annual fuel consumption of pulverized coal for steam-raising and process work. The most rapid increase in consumption is seen to be by the electricity undertakings, which as a result of present orders will exceed 10 million tons per annum by 1950.

HISTORICAL

Pulverized coal was first used in 1809 by a French engineer in attempts to burn it in an internal combustion engine. Later, British and German workers made tests on similar lines but owing to the incomplete combustion of the coal the work was abandoned.

No marked progress in the use of pulverized fuel took place throughout practically the whole of the nineteenth century, although occasional efforts were made to burn it in boilers in America, in Britain, and on the Continent. In 1894 the efforts were more successful, but this success resulted more from the nature of the application than from any great improvement or increased knowledge of combustion technique. Pulverized coal was applied in this case to the cement industry where the large refractory lined rotary furnaces or kilns formed an ideal combustion chamber for burning the coarsely ground coal then used. The problem of ash removal did not arise since the ash content of the fuel formed part of the product. With these special advantages it is not surprising that this application gave a great boost to the use of pulverized fuel. This led to the general, but mistaken, idea that low-grade dirty coal could be burned satisfactorily in pulverized form in any appliance. It was quickly found that although such fuel can be used in special cases as in the cement industry, installations using the same burners but applied to boilers gave very unsatisfactory results. The conditions for good combustion were far more exacting than in the case of cement kilns and this accounts for the many disappointments and delays which occurred before pulverized fuel was successfully burned in boiler plants. Much fundamental and development work has been carried out to overcome the difficulties encountered

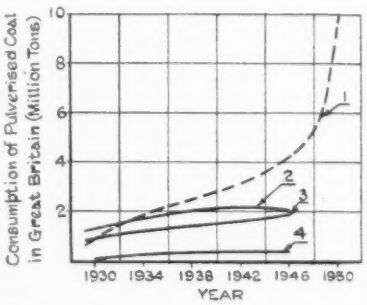

Fig. 1. Consumption of pulverized coal in Great Britain.

1. *Steam for electricity undertakings.*
2. *Process work cement kilns.*
3. *Steam for industry.*
4. *Process work metallurgical furnaces.*

* Fuel Research Station, Department of Scientific and Industrial Research.

and the progress has been such that to-day it is possible to burn pulverized fuel in plant ranging in size from a central heating boiler or small metallurgical furnace consuming less than 1 cwt of coal per hour to the large power station boilers which burn some 20 tons of coal per hour.

The Possibilities and Problems of Pulverized Fuel

The normal method of burning coal has been and still is, on some form of bed, either stationary or moving, which forms part of a furnace, and which can receive air and deliver the resulting hot flue gases, together, in many cases, with a considerable amount of radiant heat to whatever it is desired to heat.

There have always been coals, however, which by reason of their smallness, ash content, tendency to cake, etc, present difficulties in this form of combustion and an attractive way out of this, which has met with appreciable success, has been to pulverize the coal to such a fineness that about 80 per cent will pass through a 200 B.S. sieve. When pulverized to this size the coal particles can be carried in an air stream and burned in suspension in a combustion chamber without the conventional grate.

As the amount of small coal produced is likely to increase as a result of increasing mechanization of the mines—at present 75 per cent of British coal is cut mechanically—successful development of this method of burning coal will add greatly to the total quantity and class of coal which can be burned efficiently.

There are, however, inherent advantages in an efficient pulverized fuel system, for many purposes, which may, and in fact do, extend the use of this form of combustion to coals which might otherwise be suitable also for conventional methods of burning.

These advantages turn largely on the fact that a stream of air containing pulverized fuel is similar in character to gaseous or oil fuel in that it can be handled through pipes and obviously has great flexibility for changes of load.

It is also found that less trouble is experienced with external deposits on boiler tubes. For all these reasons the use of pulverized fuel is increasing.

A major problem is that of selecting the type of pulverizing plant which will give the lowest capital, operational, and maintenance costs and at the same time give the required degree of fineness of product to enable efficient combustion to take place. This will vary with local conditions and the problem becomes more complex when additional factors such as the type of coal to be used and the moisture content of the coals vary over a wide range.

There are also the requirements of combustion which control the size and shape of the combustion chamber and design of burner for any particular application.

There is generally the necessity for the removal of dust from the flue gas and in the case of a very low grade fuel this may be a serious disadvantage.

In addition, there are special problems associated with the use of pulverized fuel in a prime mover.

An expansion in the use of pulverized fuel is taking place and it is estimated that by 1950 ten million tons of coal will be burned per annum for electricity undertakings as pulverized fuel, representing some 40 per cent of all the coal likely to be used for this purpose by that time.

Systems of Operation

(*a*) *Bin and Feeder System*

In one type of plant the coal is dried in an independent dryer before grinding in the mill, and the ground product is delivered from the mill to storage hoppers or bins. Special feeders at the base of the hoppers feed the fuel into one or more air streams and the air-borne fuel passes through pipes to the burner or burners as required. The air

which carries the fuel to the burner is referred to as "primary" air and its quantity is decided mainly by combustion conditions. Additional air or "secondary" air is supplied to the burner or the combustion chamber to complete the combustion of the fuel.

A typical layout of a plant, using this method of operation, and which is generally known as a "bin and feeder" system is shown diagrammatically in Fig. 2.

A modification of this system occurs in the application to small plant such as the heating boilers of cinemas, hotels, etc. In such cases the coal may be pulverized at a central depot by a distributor and delivered to the consumer in special tank wagons.

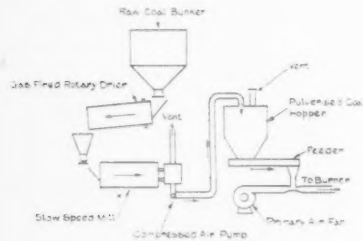

Fig. 2. Bin and feeder system.

(b) Unit System

In later designs the processes of drying and grinding the coal are carried out simultaneously inside the mill, hot air passing through the mill and removing the excess moisture. The same air carries the fuel to the burner. This method shown diagrammatically in Fig. 3 is referred to as the "unit" system, and has the advantage of simplicity and compactness. The flexibility of operation while not so good as that of the bin and feeder system, is adequate to meet the requirements of most installations. In large plants it is often improved by using one mill per burner.

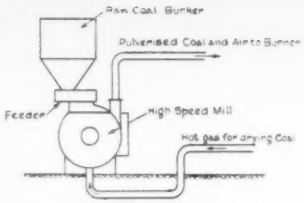

Fig. 3 Unit system.

Methods of Pulverizing Coal

Several types of mill are used for grinding the coal. They may be divided broadly into four groups as follows:

(1) Slow-speed mills;
(2) Medium-speed mills;
(3) High-speed mills;
(4) Pneumatic impact mills.

Slow-speed Mills

These embrace the ball and tube mills, which consist essentially of a horizontal steel cylinder partly filled with steel balls or rods. The mill is rotated at a speed of 25 to 60 revolutions per minute and coal is fed in axially at one end and ground to the required fineness by the steel balls or rods which cascade inside the mill when it is in motion.

In a small proportion of the mills of this type the product is discharged axially from the mill and then conveyed by means of compressed air to

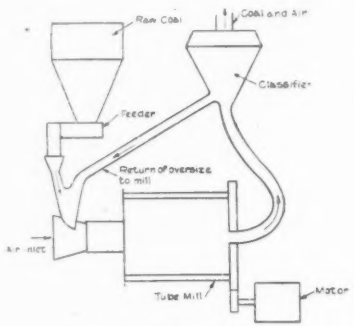

Fig. 4. Slow-speed mill.

the storage bins. No air passes through the mill and the fineness of the product is determined only by the time the coal is subjected to the action of the grinding elements.

Most ball and tube mills are air-swept, i.e., a current of air is passed through the mill as a result of which the fine product becomes airborne and can be transported to the burner, the classifier or the storage bin. A classifier controls the size of the product by making use of air velocity and changes in air direction to return oversize or coarse particles to the mill for further grinding, while the finely-ground product is carried forward with the outlet air to the burner or bin.

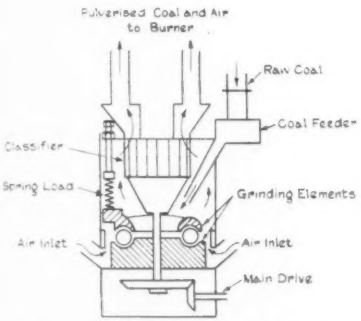

Fig. 5. Medium-speed mill—ring-ball type.

About half of the total coal which is used in pulverized form is ground in slow-speed mills. A typical layout of a slow-speed mill is shown in Fig. 4.

Medium-speed Mills

In this group of mills, operating at speeds from 100 to 350 r.p.m., there are the ring-roll and the ring-ball types which are predominant in the newer power stations designed to burn pulverized coal. The coal is ground by spring-loaded balls or rolls which run on a circular track. The designs vary considerably in detail, e.g., the circular track or ring may be inclined at any angle between horizontal and vertical, and the rolls may or may not run round the grinding ring which itself may or may not rotate. A diagrammatic sketch of a typical ring-ball mill is given in Fig. 5.

Air sweeping with classification is adopted in all types of medium-speed mills. The air serves two purposes, firstly to dry the coal and secondly to remove the ground coal from the mill and return the oversize. This limits the control of the plant and in practice it is often found that in the case of wet fuels the output is appreciably below that obtained with a drier fuel, although the fineness of grinding is the same in both

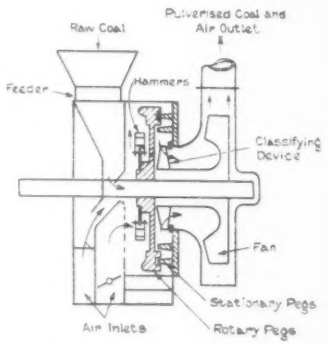

Fig. 6. High-speed mill.

cases. In general however, the medium-speed mills are able to operate with fuels containing more moisture than is permissible with slow-speed mills.

High-speed Mills

Again the design of the mills differs considerably, but all use the fundamental principle of breaking the fuel by impact and attrition at high speed. The speed of the mills varies from about 4000 r.p.m. for small plant to about 1000 r.p.m. for large units. A typical unit is shown in Fig. 6.

The pulverizer consists of one or more

cylindrical chambers in which hammers, beaters or pegged discs rotate at high speed. In some units the revolving elements act as a fan to draw through the mill a current of air which removes the finely-ground product as soon as it is formed. The classifier is often an integral part of the mill, but an independent classifier lends itself to better control of the fineness of grinding.

Since the mill operates at a high speed the size of the unit is correspondingly small, much smaller than the medium- and slow-speed mills. The capital cost is therefore low but the maintenance and "lost" time are greater than with the other mills.

When the unit system was first adopted, the high-speed mills were often used but later they were superseded by the medium-speed units mainly on the grounds of their higher overall cost of operation. The coal ground to-day in high-speed mills is only a small fraction of the total coal used in pulverized form.

In general the high-speed mill is most suitable for cases where the output is less than 1 ton per hour and under conditions where low capital outlay and minimum space requirements are at a premium.

Pneumatic Impact Mills

This group, which includes breakdown by attrition and by what is sometimes described as "explosion", i.e., disintegration of coal particles resulting from a sudden release of the pressure in the enveloping atmosphere, has had only limited commercial application although the principle is far from new. Steam and air have both been shown to be suitable working fluids, but the power consumption is rather excessive when operating on hard coals.

Most of these units use high-velocity steam or air to project granular coal against a fixed plate. Invariably a classifier is fitted and the oversize particles returned to the mill where they are reduced in size by a combination of impact and attrition. A diagrammatic arrangement of a pneumatic impact mill is shown in Fig. 7. The problem of excessive wear of the impact elements, has been countered in a recent American unit by directing a number of jets of airborne coal at a common point in space so that the impact is taken by the coal itself.

A sketch of a unit which uses the "explosive" method of pulverizing coal is shown in Fig. 8. This is known as the "Coal Atomizer" and was developed by J. C. Yellott and C. F. Knottcamp of the Locomotive Development Committee of Bituminous Coal Research Inc., Baltimore, U.S.A. The coal is supplied in particles crushed to pass through a 1/16-inch sieve, and on passing through the nozzle a rapid release of the external pressure takes place which results in the production of a great number of miniature explosions in each fragment of coal. A "cyclonizer" or attrition type pulverizer completes the process. It is understood, however, that in more recent developments an impact pulverizer has been incorporated in the unit.

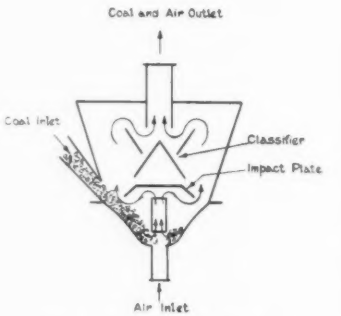

Fig. 7. Pneumatic impact mill.

Particle Size

The smaller the particle of pulverized coal the more easily will it become airborne and in general the more quickly will it burn in suspension. The cost of grinding, however, prohibits grinding all the coal to microscopic dimensions, and in practice the grinding process is not extended beyond the stage at which all the fuel becomes easily airborne and good combustion can be obtained in suspension within the combustion chamber. With most coals the practical compromise between cost of grinding and completeness of combustion occurs when the fineness of the fuel is such that about 75 per cent passes through a 200 British Standard Test Sieve.* This degree of fineness, however, must only be regarded as a general guide. In large refractory combustion chambers where a long lazy flame may be desirable, a coarser fuel may give satisfactory operation; on the other hand in a confined water-cooled combustion chamber such as the furnace of a shell type boiler a finer product is desirable and the fraction which passes through a 200 B.S. Test Sieve is generally increased to about 80 per cent. The fineness of grinding required also depends upon the type of fuel, for instance, with a low volatile fuel such as anthracite it is necessary to grind finer than in the case of a high volatile coal which in turn is ground finer than is necessary for a fuel such as pitch.

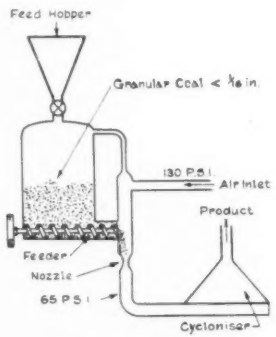

Fig. 8. Coal atomizer.

The particle size distribution of pulverized coal has been shown by many workers to follow closely to an exponential law as outlined by Rosin and Rammler, i.e.,

$$R = 100E^{-bxn}$$

where R = percentage residue on a sieve having an opening of x microns, E is the base of Napierian logarithms and b and n are constants. Experiments carried out at the Fuel Research Station confirm this general view but show that with some mills the constants vary appreciably with the kind of coal and that in most pulverizers divergencies from the exponential law occur in the range of particle sizes greater than 124 microns diameter.

In connexion with the measurement of particle size it is of interest to note that in America, Professor Hottel, working on diesel oil sprays, and in Britain, J. R. Joyce, working on the size of the droplets in the spray of oil burners for gas turbines, have both shown that the droplets follow approximately the Rosin-Rammler law, and, further, that the size of the droplets in an oil spray is of the same order as that of pulverized coal.

Combustion

The main difference between the combustibility of oil and pulverized coal is the time required to burn each fuel completely. The time required to burn pulverized coal in combustion chambers for boilers varies over the range of 0·2 to 0·8 seconds, depending upon the application and the type of burner and class of coal used, as compared with 0·01 seconds to burn kerosine in the combustion chamber of an aero gas

* The aperture size of a 200 B.S. sieve is 0·003 in = 76 microns (1 micron = 0·001 mm).

turbine. This in turn affects the rate of heat release which can be obtained in a given volume of combustion chamber and experience has shown that this can vary appreciably with the type of application: Table I gives the heat release in B.Th.U. per cu.ft. per hour per atmosphere for a number of practical applications and it will be seen that the rate of heat release is determined more by the rate at which heat can be taken away from the gas than the rate at which fuel can be burned. The rate of heat release is also affected by the size of the combustion chamber for all fuels. The ratio of surface area/volume of a combustion chamber decreases with increase of size and hence the heat release, which is transmitted through the walls decreases with the increase of the size of the combustion chamber.

TABLE I

Rates of Heat Release

Fuel	Application	Rate of Heat Release B.Th.U/ cu.ft/hour/atm
OIL		
Fuel oil	Marine boiler	300,000
Kerosine	Gas turbine	5,000,000
Gasoline	Aero engine	100,000,000
COAL		
Pulverized	Water tube boiler	15,000–40,000
Pulverized	Shell type boiler	150,000
Pulverized	Vortex combustion chamber	500,000
Small	Chain grate, water tube boiler	40,000–100,000

PULVERIZED FUEL BURNERS

The burners which are used for pulverized fuel vary in type and design as widely as those used for burning oil. Pulverized fuel burners may be classed in two main groups, firstly those designed to burn the fuel slowly with a long flame travel and secondly those designed to burn the fuel as rapidly as possible and which are generally referred to as short-flame burners.

The long-flame burners are very simple in design and many by virtue of their shape are often referred to either

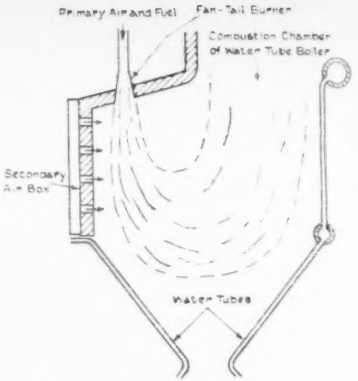

Fig. 9. Long-flame fan-type burner.

as fan-tail or as straight-shot burners. In this type the coal, carried by the primary air leaves the burner face through one or more rectangular openings as shown in Fig. 9, and the air required to complete combustion of the fuel is introduced round the primary air nozzle and, in some cases, also in stages through ports in refractory front walls. Burners of this simple form although of early design find plenty of applications in modern plant.

Short-flame burners may be divided into two classes, in the first of which rapid mixing of the coal and air to promote good ignition and combustion of the fuel is obtained by means of a high degree of turbulence. The second class is designed to give controlled mixing by introducing the primary air and fuel in small elements, each of which is surrounded by secondary air. In this manner the flow is stream-lined but the air is brought into intimate contact with the fuel and good control of ignition and combustion is obtained.

As in the case of gas or oil burners, the velocity of the inflammable mixture of air and fuel at the face of the burners corresponds to the velocity of the flame propagation of the air-coal mixture but "flash back" is avoided by using

much higher velocities within the burner itself. With high volatile fuel the mixture strength is not critical and good ignition is obtained over a wide range of loads without changing the volume of the primary air. With low volatile fuels, it is advantageous to run with the mixture which is most easily ignited.

In order to assist ignition of the fuel when starting up and to maintain good ignition during operation, a refractory ring or cone is built round the burner; very often it consists merely of a recess in the refractory wall.

Fig. 10 shows a pulverized fuel burner of the stream-lined type known as the "Multi-Jet" burner which was developed at the Fuel Research Station.

Problem of Ash Removal

Since pulverized fuel is airborne on entering a combustion chamber and burns in suspension, most of the ash and partly-burnt fuel is carried away from the boiler by the flue gases. This may account for as much as 75 per cent of the ash in the fuel as compared with about 15 per cent in the case of a stoker-fired unit.

The methods adopted for removing the dust in the flue gas from pulverized fuel installations vary considerably in type and design; electrostatic precipitators, multi-cyclone units and water washers have all been used with satisfactory results. For many years the electrostatic precipitator has been regarded as most suited for large pulverized-fuel plant, partly because it can deal with the very small particles of dust without the use of water and partly because of low power consumption and low maintenance costs. More recently, developments in the design of multi-cyclone type of plant have so improved its performance on pulverized fuel dust as to enable it to compete with electrostatic precipitators, and it may become more popular in the future.

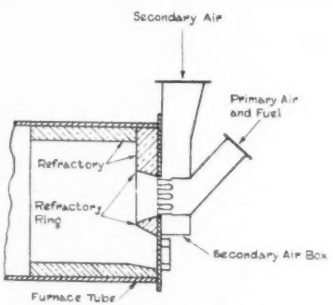

Fig. 10. Short-flame multi-jet burner fitted to a Lancashire boiler.

At the Harrogate Conference, it was suggested by a number of speakers that a combined unit in which the coarse grit and dust were removed in a simple form of cyclone cleaner and the remaining dust in an electrostatic precipitator was probably the best solution to the dust removal problem.

The removal and final disposal of the collected dust in pulverized fuel plants is a serious problem. In some plants, even where the dust is collected by a dry method, a wet method is used to transport the dust from the plant in the form of a slurry for final disposal. At present most of the dust is dumped at sea or on waste land but it becomes more and more desirable to find a use for it. From time to time attempts have been made to use the dust for such purposes as a filler for road making, for making bricks or concrete slabs, etc. All these uses have been shown to have technical possibilities but so far they have proved to be economically less attractive than normal methods of manufacture.

The Use of Pulverized Coal in a Prime Mover

The first work of any practical significance with regard to the use of pulverized coal in an internal combustion engine was done in Britain by MacCullum, who carried out research during the period 1890 to 1901. During the last year of this period he exhibited

a working model engine in Glasgow. Dr Diesel, of Germany, took out his original patent in 1892, and made many unsuccessful attempts to run an engine on pulverized coal, before changing over to oil. Subsequently the work was taken up by Pawlikowski, who succeeded in arousing the interest of the whole technical world by the claims he made for the performance of a number of oil engines which he had converted to operate on pulverized brown coal at the Kosmos Works in Görlitz. In spite of the technical success achieved no great development took place and today the considered opinion of the German engineers who have worked on this problem, is that the pulverized fuel engine has very little hope in the near future of competing successfully with existing forms of prime movers on an economic basis.

In 1936, however, the German scientists were very optimistic concerning the future of this work, and about the same time the Fuel Research Station in Great Britain carried out investigations to determine the magnitude of cylinder wear when operating on British coals and to develop methods of reducing it. The method adopted was to inject coal ash at an appropriate constant rate into the carburettor air intake of a single-cylinder gasoline engine operated on gasoline. Using many different combinations of liner, piston and piston ring materials, the effect of rate of feed of coal ash and fineness of ash on wear were examined. The results of these investigations indicated that by a suitable choice of materials the cylinder wear could be reduced to about one-seventieth of that obtained with the ordinary cast-iron liner, piston, and piston rings.

Encouraged by the success of the wear tests the Fuel Research Station converted one cylinder of a two-cylinder slow-speed diesel engine to operate on pulverized coal. Most of the mechanical problems had been overcome and numerous tests made when the programme was shut down at the outbreak of war. There still remained, however, many combustion problems. Incidentally it was found that brown coal was far more suitable than bituminous coal for combustion in this engine.

Although pulverized coal is now regarded as uneconomic for use in a converted oil engine, the future may show that it is economic when applied to the gas turbine.

Experimental work on the use of pulverized coal in the gas turbine is at present in progress in America, Switzerland, and Britain. The problems to be overcome to make it a success are many, but the obvious advantages which would be derived from it are sufficient to provide the incentive for research and development. The most publicized work on pulverized coal for use in gas turbines is the American project for locomotives where it is expected to have two full-scale units in operation next year. This work is being carried out under the direction of J. I. Yellott, Director of Research of the Locomotive Development Committee of Bituminous Coal Research Inc.

The major problems involved are feeding of the fuel under pressure, ignition and combustion in a confined space, mixing of hot gases with air to cool it to the operating temperature, removal of dust from the gas at high temperature and prevention of harmful deposits on the turbine blades. The list of problems is longer than those for firing heavy oil, but they should not be unsurmountable.

In conclusion, it is clear that although in certain fields coal can never compete with oil, it is possible by pulverising it to confer upon it some of the advantages of oil. In this way an improvement can be made in the performance to be obtained from coal, and particularly from small coal the proportion of which must inevitably increase as mechanization of the mines proceeds.

TRINIDAD PETROLEUM INDUSTRY IN 1947

REPORTING on the petroleum industry of Trinidad during 1947 the acting Inspector of Mines and Petroleum Technologist, W. N. Foster, states* that wherever possible materials for the industry were purchased in the U.K. in preference to hard currency countries. Thus, in 1947 these imports from the U.K. had a c.i.f. value of $6,822,090 in comparison with $1,438,971 in 1945.

PRODUCTION AND DRILLING

Total production of crude oil during 1947 was 20,520,554 barrels, an increase of 1·42 per cent over the preceding year. Average number of wells producing during 1947 was 1876, and of the total production 60·2 per cent was produced from flowing wells, 3·5 per cent by gas/air lift, 30 per cent by pumping, and 5·8 per cent by plunger lift. Average daily production per well was 30 barrels, a slight decrease on the 1946 figure of 30·4 barrels and 11 barrels less than the peak year of 1940, when the figure was 41 barrels.

The decline in daily average per well is attributed by the inspector to, first, the greater attention paid to artificial lift wells and, secondly, the daily average per flowing well having fallen from 79 brl/day in 1940 to 54·2 in 1947.

TRINIDAD PETROLEUM INDUSTRY

	PRODUCTION		Crude	EXPORTS	
	Crude oil	Natural gasoline	to stills	Crude oil	Refined products
	In 1000 barrels				
1939	19,680	159	19,415	217	17,383
1940	22,128	208	22,060	228	19,945
1941	20,393	219	20,812	161	15,690
1942	21,962	197	21,914	—	19,063
1943	21,286	182	21,086	—	15,860
1944	21,543	185	22,498	—	19,754
1945	21,000	182	23,170	—	20,651
1946	20,142	187	22,713	263	20,169
1947	20,433	181	25,281	881	22,045

During 1947 the number of wells completed was 157 compared with 108 in 1946. Total footage drilled during the year amounted to 644,689, an increase of 111,510, or 20·9 per cent over the 1946 total of 533,209 ft. Average depth per well was 4155 ft, a decline of 12·9 per cent from the 1946 figure.

REFINERIES

Total topping capacity of the refineries operating in Trinidad during 1947 was 95,000 brl/day, in addition there was a daily cracking capacity of 50,000 brl. Crude run to stills in the year amounted to 25,281,000 brl, an increase of 11·3 per cent over 1946.

Three natural gasoline plants were in operation, two being charcoal absorption plants and the other an oil absorption plant. A little compression gas is also made.

CONTRIBUTION TO REVENUE

In 1947 the oil industry contributed in direct taxation 16·8 per cent of the Colony's total revenue and, by reason of increased income tax and royalties, it is expected that the 1948 contribution may reach 25 per cent.

ASPHALT INDUSTRY

Production of natural asphalt from the Pitch Lake was 87,346 tons compared with 93,851 tons in 1946, and 63,118 tons in 1945.

*Trinidad and Tobago: Administration Report of the Mines Department, 1947. Government Printer, 1948. 60c.

Continued from page 9

engines, and for oil test purposes it was desirable to have standard supplies. Considerable attention was being directed towards engine tests under relatively cool running conditions which might aggravate the effects of fuel on the behaviour of the lubricant.

New engines are being developed specifically for laboratory testing, and a description was given of a design which had recently completed a 100-hour type test at the Sunbury research laboratory and which embodied several novel features.

SCUFFING AND WEAR

BOTH fundamental and practical lubrication problems were discussed before about thirty-five members of the Stanlow Branch at their November 17, 1948, meeting held at Thornton, when a paper entitled "Scuffing and Wear—Recently Developed Methods for Investigating some of the Factors Involved" by H. F. Kenyon, S. G. Daniel, and T. B. Lane was read by Mr Daniel.

In some recent studies on the basic phenomena of lubrication, the twin problems of the reduction of wear and the prevention of "scuffing" (or incipient seizure between metallic surfaces sliding upon each other) have been approached along three main lines of investigation in the course of which the following three highly specialized pieces of apparatus have been evolved:

(1) The Pin-and-ring Machine, in which a flat-ended pin wears a track on a rotating flat ring. This was designed to enable the problem of wear between parallel surfaces to be tackled at the fundamental level.

(2) The Reciprocating Wear Machine, in which a cylindrical slider rubs to and fro against a flat plate. Here the emphasis is upon the specific problem of wear between the piston rings and cylinder walls of an internal combustion engine.

(3) The Two-ball Machine, in which balls in contact rotate with a combined sliding and rolling motion. This was specially designed to enable the problem of the scuffing of gear teeth to be studied under simplified and controlled conditions.

In the paper the machines were described in outline, their mode of operation being explained, and some preliminary results obtained with them, presented and discussed. The influence of various factors such as viscosity, temperature, presence and nature of additive, constructional materials and surface finish of the test pieces, and sliding speeds were considered.

After the paper had been presented, the authors (who may be said to have been appearing on their home ground) were subjected to an hour's barrage of questions by a keenly interested audience, until the chairman had, owing to time considerations, to close the meeting by calling on Dr Davies to move a vote of thanks.

As one of the authors, Mr Lane, was abroad, his place in the discussion was taken by E. T. Hutt.

On November 24 about twenty-five members paid a visit to the Hawarden Bridge Steel Works of Messrs John Summers and Sons Ltd. The party consisted of those unable to join in the first visit to these works on September 15 (see *I.P.Review*, 1948, **2**, 347) and which had been so successful and so much enjoyed that Messrs Summers had agreed to arrange for this second Stanlow party to make this visit.

IRAN AERIAL SURVEY

RECENTLY an expedition left England for Iran to carry out an extensive survey of areas of unchartered mountains and deserts. The work is being carried out by Hunting Aerosurveys Ltd. on behalf of the Anglo-Iranian Oil Co. Ltd., and is expected to take two or three years with the expedition in the field for six months each year.

The aircraft being used is a modified Bristol Freighter, Type 170, and over one ton of photographic equipment has been taken in addition to air-survey operating gear. The aircraft has been modified in the light of experience gained in 1947 to provide greater convenience for the flight crew, who will be operating mostly at a height of over 20,000 ft.

STEEL IN INDUSTRY

AN interesting film entitled "Tools for the Job" has recently been completed by Arthur Balfour & Co. Ltd. The film is a 16-mm talkie in monochrome and lasts for about 40 minutes. The first part shows in brief outline the many processes involved in the production of high-grade tool steel. Melting, forging, and rolling are all illustrated, as are the various modern scientific instruments used in the rapid determination of the properties of a particular melt.

In the second part of the film many examples are given of the part which steel tools play in the manufacture of a multitude of products.

The film is available on loan on application to the company at Capel House, 62 New Broad Street, London, E.C.2.

STANLOW BRANCH

Corporate members of the Institute whose business addresses are in the Stanlow Branch area and who are not already enrolled as members of the branch are requested to advise the Branch Secretary (J. G. Hancock, c/o "Shell" Refining and Marketing Co. Ltd., Stanlow Refinery, Ellesmere Port, Cheshire). They will then be included in the branch register and receive notices of branch activities.

BRITISH OIL REFINERIES

In a written reply to a question in Parliament on December 9, the Minister of Fuel and Power said: Work has started on the construction of four plants at Llandarcy, Grangemouth, Stanlow and Shellhaven, which will increase refining capacity in this country by about 9½ million tons a year. The total cost will be approximately £46 million and it is expected that the projects will be completed at various times between the end of 1949 and the end of 1953. Other plans for extending refining capacity are being discussed with the companies concerned. If they are all carried out, United Kingdom capacity should, in about four years, be capable of processing nearly 20 million tons of oil as compared with approximately 2½ million tons in 1947.

PETROLEUM IN PARLIAMENT

COAL-OIL RESEARCH

The Minister of Fuel and Power was asked on December 9 what research was being carried out in the U.K. on production of oil from coal and what were the plans for developing such production. In a written reply the Minister said: Experiments have been carried out at the Fuel Research Station of the Department of Scientific and Industrial Research over several years and are being continued. The staff of that station has also investigated processes operated on a considerable scale in Germany and keeps in close touch with work in the U.S.A. As regards the second part of the question, the possibilities of producing oil from coal are under constant review. While technical developments hold some promise that the very high costs will be reduced, perhaps through the production of valuable chemical by-products, they do not yet justify plans for operation on a commercial scale in the U.K.

LUBRICANTS

Asked on December 13 if he would consult the British Standards Institute with a view to producing specifications of lubricating oils for various purposes, the Minister of Supply said he would not. He added that except that his Ministry was interested in the standardization of oils for Service vehicles he had no responsibility for specifications of lubricating oils.

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FORTHCOMING MEETINGS

INSTITUTE MEETINGS

Production from Condensate Reservoirs. L. C. Stevens and P. B. Boots. At 26 Portland Place, London, W.1, 5.30 p.m. (tea 5 p.m.), February 9.

Modern Trend in Tanker Construction. John Lamb. At 26 Portland Place, London, W.1, 5.30 p.m. (tea 5 p.m.), March 9.

The Viscosity of Aero-Engine Oils at Low Temperatures. S. G. Daniel. At 26 Portland Place, London, W.1, 5.30 p.m. (tea 5 p.m.), April 13.

LONDON BRANCH

The Influence of Tetraethyl Lead on Engine Design and Performance. Air-Comdr. F. R. Banks. At 26 Portland Place, London, W.1, 6 p.m. (tea [1*s.*] 5.30 p.m.), February 22.

International Trading Problems and the Oil Industry. P. M. de Veulle. At 26 Portland Place, London, W.1, 6 p.m. (tea [1*s.*] 5.30 p.m.), March 22.

SCOTTISH BRANCH

Organic Chemicals from Petroleum. W. L. Wood. At Engineering Centre, Glasgow, 7.30 p.m., February 23.

MEETINGS OF OTHER SOCIETIES

The Stability of Emulsions. A. S. C. Lawrence. The Chemical Society, at Chemistry Dept., Bristol University, 7 p.m., February 10.

The Use of Factorial Experiment for Investigating Chemical Processes. K. A. Brownlee. Society of Chemical Industry (London Sect.). At 2 Savoy Hill, London, W.C.2, 6 p.m., March 4.

Solvent Extraction as a Unit Process. J. C. Wood-Mallock. Institution of Chemical Engineers, at Reynolds Hall, College of Technology, Manchester, 3 p.m., March 12.

The Principles of Diesel Engine Waste Heat Recovery. T. R. Houston. Diesel Engine Users' Assoc. At. Caxton Hall, London, S.W.1, 2.30 p.m., March 17.

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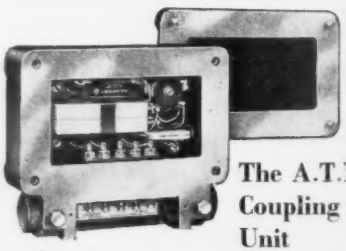

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This unit permits through speech and ringing, yet prevents the passage of dangerous voltages into the unsafe area. It consists of a series impedance network shunted by a disc of "Atmite"—a compound which has a high impedance at normal signalling and speech voltages, but has a low impedance at higher voltages. The change to low impedance takes place at voltages well below the dangerous level.

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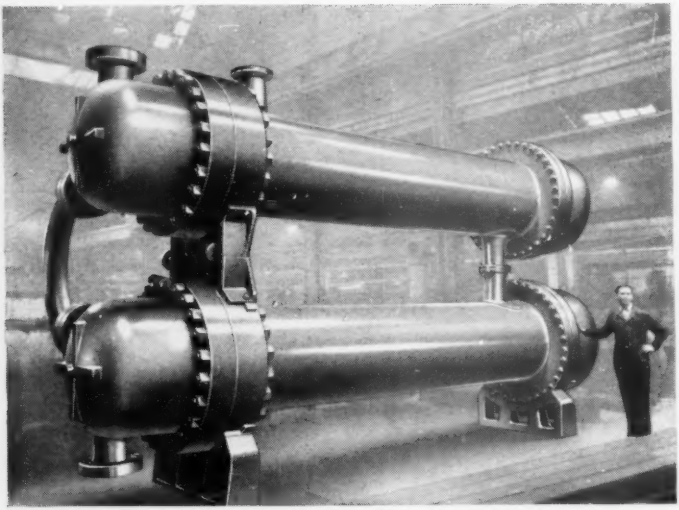
AUTOMATIC TELEPHONE & ELECTRIC CO. LTD. Export Dept. Norfolk House, Norfolk Street, London, W.C.2

TEMple Bar 9262. Inland Telegrams: Autelco, Estrand, London. Cables: Autelco, London. Strowger Works, Liverpool, 7, England

A6392-C2

HEAT EXCHANGE EQUIPMENT



HIGH PRESSURE HEAT EXCHANGERS

Surface per Unit	... ...	2170 sq. feet
Working Pressure in Tubes	...	1500 lb. per sq. inch

These two Units form part of a battery comprising 60 similar Units and having a Crude Oil throughput of 4½ million gallons per day.

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